SOME RELATIONSHIPS BETWEEN WATER FERTILITY AND EGG PRODUCTION IN BROWN TROUT (*SALMO TRUTTA*) FROM MONTANA STREAMS

Lawrence L. Lockard[1]

Abstract.— Relationships between water fertility (as measured by conductivity and alkalinity) of 17 Montana streams and the attainment of sexual maturity and fecundity of their resident female brown trout were studied. Fish from the streams having conductivity and alkalinity levels greater than 100 micromhos/cm and ppm $CaCO_3$, respectively, were younger at sexual maturity than fish from waters with lower levels. The attainment of earlier sexual maturity in fish from the former streams could not be completely explained on the basis of greater growth rates. Fish from the stream having the highest levels of conductivity had the slowest growth rate but became sexually mature at the youngest age. A positive relationship was found between chemical fertility of streams and the fecundity of their fish. However, in the stream having the highest levels of conductivity, fish were the least fecund. It was concluded that the chemical fertility of these streams is generally related to the age at sexual maturity and fecundity of fish.

The size and age at sexual maturity and the fecundity of female fish appear to be related to features of their environment. In Pennsylvania brown trout (*Salmo trutta*) from infertile waters had a smaller proportion of mature fish per age class and smaller weight of eggs than comparable fish from fertile waters (McFadden, Cooper, and Anderson 1965). Scott (1962) and Bagenal (1969) demonstrated that rainbow trout (*Salmo gairdneri*) and brown trout, respectively, brought a lower number of eggs to maturity under reduced nutritional levels than fish on higher levels of nutrition.

This study is an attempt to determine the relationships between the conductivities and alkalinities of Montana streams and (1) the size and age at sexual maturity and (2) the fecundity of the brown trout in those streams. Field collections were made from 8 September to 23 October 1972 and from 1 September to 19 October 1973.

Methods

A total of 449 female brown trout were collected by electrofishing at sites on streams in the Clark Fork of the Columbia River and in the Yellowstone and Missouri River drainages (Fig. 1). These streams had a wide range of physical and chemical conditions (Table 1).

At least one fall, winter, and summer measurement of conductivity and alkalinity was made at each collecting site. The field measurements from each stream were averaged with the yearly conductivity and alkalinity averages obtained from Water Resources Data for Montana (U.S.G.S. 1972) where available. Discharge values were obtained by averaging available yearly values from the above U.S.G.S. records with values measured or estimated by fisheries biologists of the Montana Fish and Game Department.

All fish were collected during September and October of 1972 and 1973 (Table 2). Fish taken were preserved in 10 percent formalin and later washed in water and stored in 40 percent isopropyl alcohol. Fixation in formalin causes specimens to shrink about 3-4 percent in length and increase 5-12 percent in weight (Parker 1963). After preservation, fish were measured, weighed, and scale samples were removed for age determinations. Each fish was classified as mature or immature according to the condition of the eggs in its ovaries. Mature fish containing eggs in a gradient of sizes were not used in the fecundity analyses because the number of eggs is reduced by resorption throughout the maturation period, and regressing eggs could not be distinguished from maturing eggs in these fish. Only fish having distinct recruitment and maturing eggs without intervening size classes of eggs were used in fecundity work. The ovaries from these fish were removed and the number of maturing eggs determined by actual count.

The streams from which collections

[1]Current address: 312 South Grant Avenue, Pierre, SD 57501.

TABLE 1. Selected chemical and physical features of streams sampled.

Collection site no.[1]	Location of site	Conductivity (micromhos/cm)	Alkalinity (ppm $CaCO_3$)	Discharge (C.F.S.)
1	Rock Cr.	70	49	169
2	St. Regis R.	80	51	555
3	Big Hole R.	207	117	1,125
4	W. Gallatin R.	230	118	791
5	Madison R.	249	107	1,409
6	Baker Cr.	317	154	70
7	O'Dell Cr.	348	167	100
8	L. Prickley Pear Cr.	358	195	69
9	E. Gallatin R.	360	195	400
10	Shields R.	402	221	159
11	Flagstaff Cr.	405	197	5
12	Beaverhead R.	521	193	405
13	16 Mile Cr.	522	195	50
14	So. F. Musselshell R.	561	243	83
15	Little Blackfoot R.	612	188	105
16	Bluewater Cr.[2]	798	209	18
17	Big Horn R.	805	188	3,500
18	Bluewater Cr.[3]	1,387	214	28

[1]See Figure 1
[2]Section above Bluewater Fish Hatchery
[3]Section below Bluewater Fish Hatchery

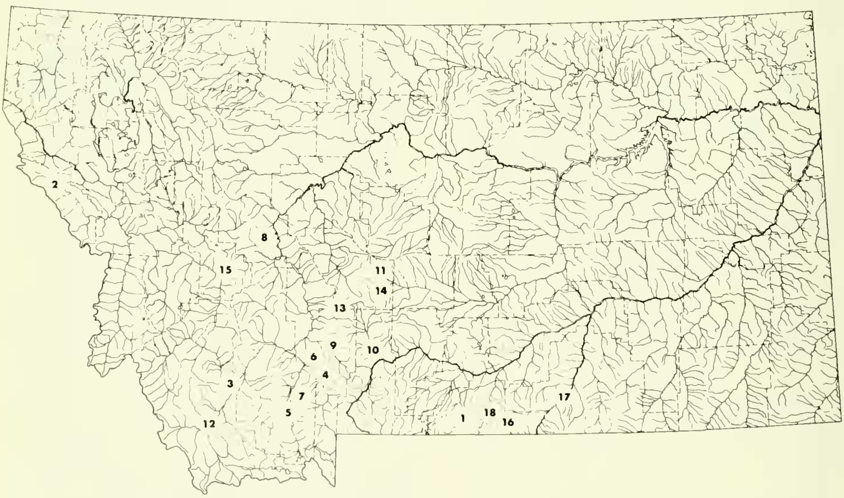

Fig. 1. Map showing location of collecting sites.

were made were grouped into classes primarily on the basis of similarities in conductivities following the technique used by McFadden et al. (1965). Streams from which collections 1 and 2 were taken each had less than 100 units of conductivity and alkalinity and formed Class I. Streams from which collecting sites 3 through 18 were located had alkalinity values above 100; thus conductivities were used as the primary indicator of water fertility. Class II contained streams on which collection sites 3 through 11 were located. These streams had conductivities ranging from 207-405 micromhos/cm at 25 C. Streams of collecting sites 12 through 15 had conductivities of from 521-612 and comprised Class III except for the analysis of size and age at sexual maturity in which Stream 17 was includ-

TABLE 2. The location, date, and number of fish collected.

Collection site	1972 Collection date	1972 Number fish	1973 Collection date	1973 Number fish	Total fish
1 (Rock Cr.)	Oct. 13	16	Sept. 14	17	33
2 (St. Regis R.)	....	....	Sept. 1	22	22
3 (Big Hole R.)	Oct. 9	17	....	....	17
4 (W. Gallatin R.)	Oct. 18	17	Sept. 25	11	28
5 (Madison R.)	Sept. 21	13	Sept. 20	19	32
6 (Baker Cr.)	Oct. 10	17	Sept. 26	9	26
7 (O'Dell Cr.)	Sept. 22	11	Sept. 21	8	19
8 (L. Prickley Pear Cr.)	Oct. 23	16	Oct. 2	17	33
9 (E. Gallatin R.)	Sept. 18	15	Oct. 4	16	31
10 (Shields R.)	Oct. 6	11	Sept. 24	6	17
11 (Flagstaff Cr.)	Oct. 9	9	....	....	9
12 (Beaverhead R.)	Sept. 26	14	Oct. 17	9	23
13 (16 Mile Cr.)	Sept. 11	13	Oct. 11	14	27
14 (So. F. Musselshell R.)	....	....	Sept. 24	13	13
15 (Little Blackfoot R.)	....	....	Oct. 1	28	28
16 (Bluewater Cr.)[1]	Sept. 8	13	Sept. 12	14	27
17 (Big Horn R.)	....	....	Sept. 15	14	14
18 (Bluewater Cr.)[2]	Sept. 8	13	Sept. 12	37	50

[1]Section above Bluewater Fish Hatchery
[2]Section below Bulewater Fish Hatchery

ed. The streams of Class II and III were combined into Class IV because their fish had similar relationships to conductivity. Class V was made up of Bluewater Creek on which collecting sites 16 and 18 were located. These collecting sites were grouped together primarily because of their high conductivities.

The fish in stream classes were statistically compared by selected procedures and techniques from "Statistical Methods" (Snedecor and Cochran 1971) and "Statistical Methods" (Arkin and Colton 1972). Additional techniques were provided by Dr. R. E. Lund, Mathematics Department, Montana State University.

RESULTS

Size and Age of Sexually Mature Female Brown Trout

Generally the attainment of sexual maturity of fish is dependent on size and age. Inspection of age groups within stream classes indicated an apparent tendency for a higher proportion of the larger females to be sexually mature (Table 3). To test the linearity of this trend, regressions were made on fish from age groups in stream classes showing an increase in sexual maturity with increasing length. In age group I, fish from Class V streams showed a significant positive linear relationship between length and sexual maturity ($P = 0.001$). In age group II, a significantly higher proportion of larger fish were sexually mature in Stream Classes I, II, III, and IV with P values of less than 0.05. In age group III$^+$, fish from Stream Classes II and IV had significant positive linear relationships between length and sexual maturity ($P<0.05$). McFadden et al. (1965) found a tendency within a given year class for a higher percentage of larger than smaller fish to be sexually mature.

The effect of age on the attainment of sexual maturity in fish was determined by comparing the proportions of sexually mature fish between age groups by a technique of R. E. Lund. Only 2 percent of age group I fish 8.0-13.9 inches long from Class IV streams were mature, while 34 percent of comparably sized fish in age group II were mature. The difference in proportions was significant with a $P = 0.001$. There were significantly fewer mature 6.0-8.9 inch fish from Class V streams in age group I than in age group II ($P = 0.08$). These combined probability values demonstrated a significantly ($P = 0.001$) higher proportion of age II fish were mature than age I fish. Significantly more of size group 10.0-19.9 inch fish from Class IV streams were mature at age III$^+$ than age II ($P = 0.001$). This relationship of a higher percentage of older females being sexually mature than younger females in the same size group has been reported by McFadden et al. (1965).

TABLE 3. Size and age of sexually mature female brown trout by stream classes.

Age group	Length (inches)	Stream classes I #Fish	I %Mat.	II #Fish	II %Mat.	III #Fish	III %Mat.	IV #Fish	IV %Mat.	V #Fish	V %Mat.
I											
	4.0-4.9	0	....	0	....	0	....	0	....	5	0
	5.0-5.9	0	....	0	....	0	....	0	....	3	33
	6.0-6.9	3	0	0	....	0	....	0	....	16	31
	7.0-7.9	4	0	1	0	0	....	1	0	17	47
	8.0-8.9	1	0	7	0	2	0	9	0	6	100
	9.0-9.9	1	0	6	0	5	0	11	0	0	....
	10.0-10.9	0	....	11	0	10	0	21	0	0	....
	11.0-11.9	0	....	0	....	7	0	7	0	0	....
	12.0-12.9	0	....	0	....	2	0	2	0	0	....
	13.0-13.9	0	....	0	....	2	50	2	50	0	....
	Total	9	0	25	0	28	4	53	2	47	43
II											
	6.0-6.9	0	....	0	....	0	....	0	....	1	100
	7.0-7.9	0	....	0	....	0	....	0	....	6	67
	8.0-8.9	2	0	1	0	0	....	1	0	6	83
	9.0-9.9	9	33	5	0	2	0	7	0	5	100
	10.0-10.9	6	33	16	13	9	11	25	12	1	100
	11.0-11.9	1	100	29	31	8	0	32	28	1	100
	12.0-12.9	2	100	23	61	9	22	32	50	4	100
	13.0-13.9	1	100	9	67	7	57	16	63	0	....
	14.0-14.9	0	....	19	84	3	100	22	86	0	....
	15.0-15.9	0	....	3	67	5	80	8	75	0	....
	16.0-16.9	0	....	1	100	4	100	5	100	0	....
	17.0-17.9	0	....	1	100	3	100	4	100	0	....
	18.0-18.9	0	....	0	....	2	100	2	100	0	....
	19.0-19.9	0	....	0	....	1	100	1	100	0	....
	Total	21	43	107	48	48	50	155	48	24	88
III+											
	8.0-8.9	0	....	0	....	0	....	0	....	1	100
	9.0-9.9	0	....	0	....	0	....	0	....	1	100
	10.0-10.9	3	67	1	0	0	....	1	0	0	....
	11.0-11.9	8	75	3	67	1	100	4	75	2	100
	12.0-12.9	1	100	4	100	2	100	6	100	0	....
	13.0-13.9	5	100	12	92	6	100	18	94	0	....
	14.0-14.9	2	50	13	92	4	75	17	88	1	100
	15.0-15.9	2	100	16	100	9	100	25	100	1	100
	16.0-16.9	2	100	14	93	1	100	15	93	0	....
	17.0-17.9	1	100	8	100	2	100	10	100	0	....
	18.0-18.9	1	100	5	100	3	100	8	100	0	....
	19.0-19.9	0	....	3	100	1	100	4	100	0	....
	20.0-20.9	0	....	1	100	0	....	1	100	0	....
	Total	25	84	80	94	29	97	109	95	6	100
Grand Total		55	55	212	59	105	51	317	57	77	61

Comparisons were made of the proportions of sexually mature female brown trout between stream classes using a method of Arkin and Colton (1972). No significant difference (0.05 level) was found in the proportion of mature females in Class II and III streams either by age group or grand total so further comparisons by this method were made between the fish of Stream Classes I, IV, and V.

There was no significant difference between Class I and IV streams in the proportions of mature females in age group II; however, Class IV streams had a significantly higher proportion of mature females in age group III+ than did Class I streams ($P = 0.054$). Class V streams had a higher proportion of sexually mature females than both Class I and IV streams in both age group I ($P = 0.014$ and 0.001, respectively) and age group II ($P = 0.001$ and 0.001, respectively).

Fisher's randomization test (Bradley 1968) was used to further test the hypothesis that maturation increases as conductivity increases. The probability of obtaining the increased proportions of mature fish in all age groups with the increasing conductivities in Stream Classes I, II, III, and V (Table 3) is P = 0.00014.

The class I and IV streams in this study were similar in conductivity and alkalinity to the infertile and fertile streams in the studies of McFadden and Cooper (1962) and McFadden et al. (1965). In the latter study, fish from fertile waters attained maturity at an earlier age than those from infertile waters. This was attributed partially to a greater growth rate of fish in fertile waters; however, the authors also found higher proportions of fish of the same size and age were sexually mature in fertile streams.

In the present study, this latter relationship was not observed among fish from Class I and IV streams. Instead, higher proportions of females of a given size and age tended to be mature in the less fertile Class I streams. The differences in age at maturity between fish from Stream Classes I and IV, therefore, seem closely related to differences in growth rate. The distribution of sizes of specimens of given age groups do indicate faster growth rates in Class IV streams (Table 3). McFadden and Cooper (1962) also reported positive correlations between growth rates of brown trout and environmental fertility.

Class V streams had higher conductivity and alkalinity values than any of the streams studied by McFadden et al. (1965). In the more fertile waters (Class V), fish matured at younger ages than in less fertile waters (Classes I through IV); however, this early maturity in Class V streams was not due to a faster growth rate in fertile waters. That is, the smallest fish in each age group are found in the Class V streams (Table 3). Therefore, some factor other than growth rate or chronological age apparently influenced the size and age at which sexual maturity was reached by fish from the very fertile (chemically) waters of Class V.

Fecundity

Regression analyses for the number of mature eggs in a fish (dependent variable) on fish length (independent variable) were applied to the fish of the individual streams and stream classifications. T tests for the regression of numbers of eggs on lengths were statistically significant at the 0.05 level for fish from all streams and stream classifications with most probability values being less than 0.01. Flagstaff Creek and the Big Horn River were omitted from analyses because of an insufficient number of mature fish.

The regression lines of numbers of eggs regressed on fish length in stream classifications are shown in Figure 2. The regression lines with steeper slopes show a greater increase in number of eggs per increment of length than lines with lesser slopes.

Regression coefficients, slopes of the regression lines, were calculated for these regressions on each stream and stream classification (Table 4). The slopes of the stream classification regressions were tested for significant differences by a method of R. E. Lund (Table 5). Six of the 8 comparisons of slopes of regressions were significantly different at the 0.05 level.

Fish from Stream Class I were less fecund than fish from Stream Class II (Fig. 2 and Table 4). The difference between these stream classes was statistically significant at the 0.05 level (Table 5). This relationship of increased fecundity with increased conductivity is similar to that

Table 4. Regression coefficients (slopes) of streams and stream classifications.

Stream or classification	No. of eggs regressed on fish length: Regression coefficient	Std error	N
Rock Cr.	213	22	18
St. Regis R.	173	47	12
Stream Class I	254	22	30
Big Hole R.	284	40	7
W. Gallatin R.	426	83	14
Madison R.	457	64	16
Baker Cr.	164	53	13
O'Dell Cr.	248	51	14
L. Prickley Pear Cr.	236	43	16
E. Gallatin R.	218	29	19
Shields R.	252	43	16
Stream Class II	325	20	115
Beaverhead R.	172	98	15
16 Mile Cr.	143	48	15
So. F. Musselshell R.	315	112	6
Little Blackfoot R.	249	65	15
Stream Class III	286	39	51
Stream Class IV	318	18	166
Bluewater Cr.[1]	170	20	19
Bluewater Cr.[2]	113	16	21
Stream Class V	147	13	40

[1]Section above Bluewater Fish Hatchery
[2]Section below Bluewater Fish Hatchery

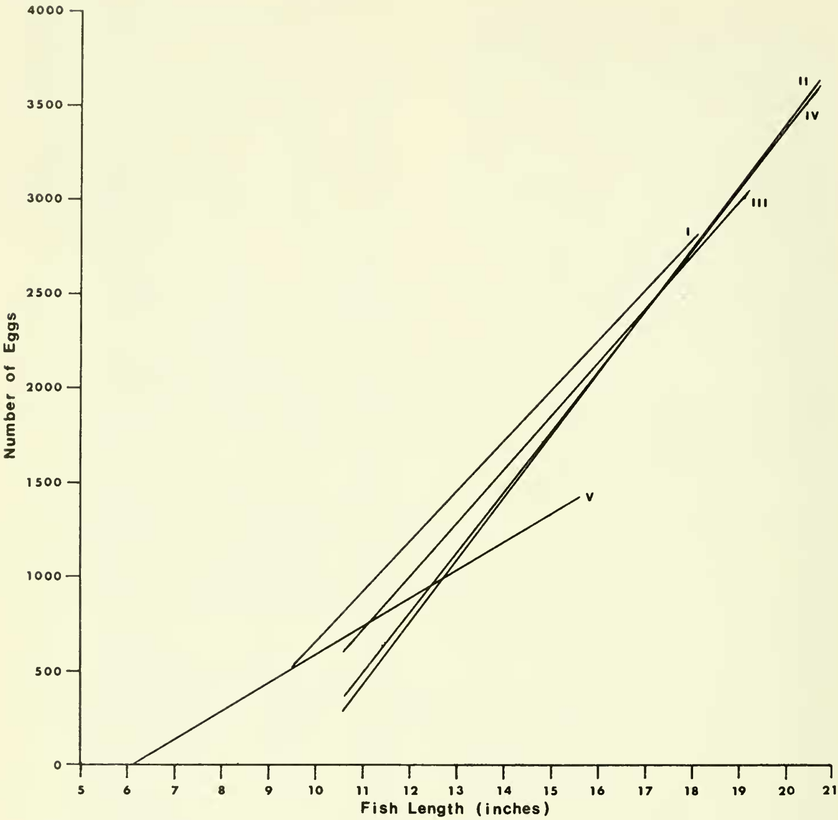

Fig. 2. The regression lines of number of eggs on length for fish in stream classifications.

TABLE 5. Comparisons between stream classes by slopes of regressions of number of eggs on fish length.

Slope comparison	Number of eggs regressed on fish length T	df	P
I vs II	2.42	77	0.018*
I vs III	0.72	46	0.475
I vs IV	2.25	73	0.028*
I vs V	4.18	47	0.000*
II vs III	0.90	75	0.371
II vs V	7.61	149	0.000*
III vs V	3.39	60	0.001*
IV vs V	7.80	174	0.000*

*Significant at the 0.05 level

found by McFadden et al. (1965) in fish from infertile and fertile streams having conductivities and alkalinities similar to those of Class I and II streams in this study.

Fish from Stream Class III appeared to be more fecund than fish from Stream Class I (Fig. 2 and Table 4). This relationship of increased fecundity with increased conductivity was not statistically significant at the 0.05 level (Table 5). Stream Class III contained streams with higher levels of conductivity than those reported by McFadden et al. (1965).

Fish from Stream Class IV (Stream Classes II and III combined) represent fish from a broad category of chemically fertile streams with conductivities from about 200 to 600 micromhos/cm. In general, these fish were more fecund (P=

0.028) than fish from Class I streams, which represent chemically infertile waters.

Fish from Stream Class V, which had the highest conductivity, had the lowest fecundity. The conductivity values of this stream were about three times greater than the highest values reported by McFadden and Cooper (1962). The above results suggest some factor other than conductivity is determining the fecundity of fish in this stream class.

Summary

An inverse relationship between chemical fertility and age at sexual maturity was found in brown trout from streams of Montana in this study. This same relationship between the chemical fertility of streams, as measured by conductivities and alkalinities, and the age of sexual maturity of brown trout from Pennsylvania has been reported by McFadden et al. (1965). They suggested this relationship was due partially to fish in fertile streams having greater growth rates. Growth rate may account for the age at maturity in fish from 16 of the 17 streams in this study, but cannot explain the age at maturity in fish from Bluewater Creek. Fish from Bluewater Creek attained sexual maturity much earlier than fish from less fertile streams; however, these fish from the stream with the highest conductivity had the poorest growth rates of all the fish studied. This shows growth rate was not the determining factor in the attainment of sexual maturity for fish from Bluewater Creek.

McFadden et al. (1965) found a positive relationship between the chemical fertility of streams and the fecundity of their fish. A similar relationship was found between chemical fertility and fecundity in fish of this study from streams having conductivities similar to those studied by McFadden et al. (1965). However, fish from Bluewater Creek, chemically the most fertile stream, were the least fecund. Generally the age at sexual maturity of fish from all stream classes and the fecundity of fish from Stream Classes I, II, III and IV appeared to be related to the chemical fertility of their streams.

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